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Sustainability as a Framework for Analyzing Socioscientific Issues

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Abstract
Scientific and environmental literacy are cornerstones of science education reform and twenty first century citizenry. The ability to make decisions about socioscientific issues is a characteristic of scientific and environmental literacy. This study uses the Sustainability Triad to explore preservice science teachers' analyses and decision-making about socioscientific issues. Results indicate that preservice science teachers do not consistently use the dimensions of the Sustainability Triad as they analyze socioscientific issues, and make decisions that are not sustainable. Recommendations for science teacher preparation programs that emphasize sustainability considerations are provided.

Keywords: socioscientific issues, scientific literacy, environmental education, sustainability, science teacher preparation

Introduction

Much of the socio-political rhetoric of the 21st century is centered on socioscientific issues and sustainable development. The need for citizens who use knowledge of scientific concepts to participate in social conversations and make decisions about socioscientific issues is epitomized in the science education community's calls for scientific literacy (American Association for the Advancement of Science, 1993; Bybee, 1997; National Research Council, 1996). Socioscientific issues are complex social dilemmas that (a) impact economic, civic and cultural affairs, (b) lack clear-cut solutions, and (c) have conceptual or technological ties to science (Sadler, 2004). Some examples of socioscientific issues include genetic screening, diet, medical treatment, and biological and chemical weapons.

Scientific literacy also entails decision-making that leads to sustainable development. Sustainable development results in practices, processes, activities, or regions that meet the needs of the present without compromising future generations' ability to meet their needs. For sustainable decision-

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making to occur, the principles, values, and concepts of sustainable development must be integrated into all aspects of education and learning (Bybee, 2008; United Nations Educational Scientific and Cultural Organization [UNESCO], 2010). The outcomes of such an education are citizens with the "attitudes, skills and knowledge to make informed decisions that would benefit themselves and others, now and in the future, and to act upon these decisions" (UNESCO, 2010).

Sustainability and sustainable development naturally fit in the science curriculum. Currently, sustainability in the form of environmental literacy is apparent in new and revised K-12 science curricula across the globe (Organization for Economic Cooperation and Development, 2005; Partnership for 21st Century Skills, 2009). Considerations of sustainability are also at the center of the curriculum of several institutions of higher education (Morrone, Mancl, & Carr, 2001). While the need to prepare sustainability-literate teachers is slowly gaining momentum (McLean, 2009; Nolet, 2009), research that examines science teachers' knowledge and actions relating to sustainable development is non-existent. Yet teachers are the most influential factor affecting the development of learners' attitudes, skills, and knowledge. The purpose of this study is to investigate the following research questions:

1. Do preservice science teachers intuitively use sustainability as a criterion for analyzing socioscientific issues?
2. What considerations do preservice teachers mostly use to inform their decisions about socioscientific issues?
3. What factors characterize preservice teachers' analysis of socioscientific issues?
4. How sustainable are preservice teachers' stances respective to selected socioscientific issues?

The Sustainability Triad

This study uses the Sustainability Triad, Sadler's (1990) conception of the social, economic and environmental aspects of sustainability, as a conceptual framework. The triad visually represents sustainability in three overlapping circles representing the social, economic, and environmental dimensions. The economic dimension of the sustainability triad is concerned with satisfying the material wealth of people through money, property, or other possessions that have an economic value measurable in price. The social dimension of the triad is concerned with maintaining and improving human living standards, shifting "the emphasis from individual right and economic wealth to community rights and social welfare of all human beings" (Herremans & Reid, 2002, p. 18). The environmental dimension is concerned with systems that preserve the integrity and continued productivity and functioning of ecosystems. Any activity, process, region, or project can be considered sustainable if it (a) lies in the sustainability domain, which is the intersection of the three circles, and (b) is characterized by congruence and lack of conflict

among the three dimensions, and (c) maintains, supports, or carries the weight or burden of all three dimensions of the Sustainability Triad over the long term (Fien & Trainer, 1993).

Herremans and Reid (2002) propose the sustainability triad as a classroom tool for the development of understanding, recognition, and implementation of the concept of sustainability. These researchers posit that using the triad as a framework for case analysis offers several advantages:

1. It helps students to conceptualize the relationships between the three dimensions of sustainability and begin to understand the dimensions more deeply by identifying activities that fit into each of the areas of overlap (conflicts or congruencies);
2. It can help students understand that the diversity of stakeholders' values may constitute a barrier to achieving sustainability; and
3. It contributes to the development of higher levels of learning including analysis, synthesis, and evaluation.

The Sustainability Triad provides students with a concrete process for identifying practices that are not sustainable (conflicts) and ones that are more so (congruencies). Identification of conflicts and congruencies between the economic, social, and environmental dimensions leads to determinations of why practices are not sustainable, followed by a discussion of the steps needed to seek a solution and move from an unsustainable position to a more sustainable position (Herremans & Reid, 2002).

Methods

The study relied on a mixed-methods approach (Creswell, 2009) to guide the collection, organization and analysis of data. Data collection occurred in the context of two sections of a middle school science methods course at a US Midwestern university. Participants consisted of 40 preservice teachers enrolled in the course. Twenty-seven of the participants were female. The preservice teachers were in the final stages of completing the science content requirements for their license. Science requirements consisted of courses in chemistry, physics, geology, astronomy, and plant structure and development. Requirements additionally included the Plants and People course and a choice between the Environmental Geology and Water and Pollution courses.

Data for this study consisted of the *Does it Matter* methods course assignment. The Does it Matter assignment requires groups of preservice science teachers to:

a) Select a socioscientific issue based on interest in general or by choosing from *Thinking scientifically about controversial issues: Clones, cats, and chemicals* (Slesnick, 2004),

b) Identify the science and technology concepts tied to the issue, and relating them to relevant state and national standards,

c) Assemble relevant media resources to deepen understanding of the issue,

d) Summarize the merits, disadvantages, and implications of the beliefs and practices of stakeholders, and

e) Take a stance on the issue and supporting it with references to prepared summary.

Eleven Does it Matter assignments were used as a data source. The title of the socioscientific issues that were the focus of these assignments are described in Table 1. Table 1 also describes the stance that each group of preservice teachers took with respect to their selected issue. Data analysis began after the course was completed and grades were submitted. Qualitative and descriptive statistical data analysis of the eleven Does it Matter assignments followed the interactive process described in Creswell (2009).

Table 1
Participants' decisions about socioscientific issues.

Issue	Stance	Number of participants
No Weapons I	No to the use of biological and chemical warfare	4
No Weapons II	No to the use of biological and chemical warfare	3
Yes Weapons	Yes to the use of biological and chemical warfare	3
E-coal	Yes to the use of energy from coal	3
E-biofuel	Yes to the use of energy from biofuel	4
E-nuclear	Yes to the use of nuclear energy	4
Allow Cats	Allow free roaming cats	3
Ban Cats	Ban free roaming cats	4
Allow Hunting	Modern humans should hunt	4
Allow GMP	Genetically modified plants should be used	4
Allow Logging	Deforestation/logging should be allowed	4

To answer the first research question, the rationales proposed in the eleven assignments were identified and categorized into one of the triad's three dimensions. An example of a rationale that was categorized as economic consists of, "Our use of biofuel will result in less gasoline import and more economic independence." An example of a rationale that was categorized as social consists of, "A downside is that radiation exposure may lead to cancer and birth defects." An example of a rationale that was categorized as environmental consists of, "Some engineered plants, like poplar, clean heavy

metal pollution from ground water." Furthermore, the frequency of rationales consistent with each dimension was calculated for each assignment and in total (Table 2). Using the data presented in Table 2, the percentage of assignments that used rationales consistent with all three dimensions of the Sustainability Triad was calculated. Similarly, the percentage of assignments using rationales consistent with only two dimensions or only one dimension was calculated respectively. These percentages are presented in the Results section. Finally, the total number of rationales proposed was calculated by assignment and overall (Table 2).

Table 2
Total number of rationales by assignment, dimension, and pro and con.

Assignment	Economic	Social	Environmental	Total	Total Pro	Total Con
Allow Hunting	4	6	2	12	10	2
No Weapons I	6	6	3	15	9	6
Yes Weapons	4	2	0	6	5	1
No Weapons II	4	4	0	8	5	3
E-Coal	6	3	0	9	8	1
E-Biofuel	13	0	6	19	13	6
E-Nuclear	5	2	5	12	7	5
Allow Logging	9	6	4	19	13	6
Allow GMP	7	7	9	23	15	8
Allow Cats	0	0	4	4	2	2
Ban Cats	4	2	3	9	5	4
Total	62	38	36	136	92	44

To answer the second research question, the rationales grouped within each dimension of the sustainability triad were subjected to an open coding process to determine the type of considerations preservice teachers use to inform their decisions about socioscientific issues. Three economic, four social, and four environmental subcategories emerged and are listed in Table 3. Frequencies and percentages were calculated for the number of rationales per subcategory (Table 3).

To answer the third research question, the rationales proposed in each assignment were categorized as pro or con, and the total number of each was calculated (Table 2). The pro category represented preservice teachers' supportive arguments, benefits or other positive consequences. The con category represented preservice teachers' counter arguments, disadvantages or other negative consequences. Next, the pro and con rationales for each of the assignments were analyzed for congruencies and conflicts between dimensions (Herremans & Reid, 2002), and the types of values apparent in

the analysis. Kluckhohn & Strodtbeck's (1961) continuum of values in the following three areas was used:

a) Only humans have value – all life has value;
b) Self-interest – community interest; and
c) Short-term vision – long-term vision

Table 3
Rationales and considerations by dimension of the sustainability triad

Dimension	Subcategory	Total	Percentage
Economic	Personal Wealth	30	22%
	Corporate Wealth	24	18%
	National Wealth	8	6%
Social	Health Care	13	10%
	Food Standards	7	5%
	Happy Life	7	5%
	Welfare and Rights	11	8%
Environmental	Pollution	18	13%
	Populations	12	9%
	Resources	3	2%
	Species	3	2%
	Total	136	100%

To answer the fourth research question, the dimensions of the sustainability triad, emerging subcategories, conflicts, congruencies, and values were used to construct descriptive cases for each of the Does it Matter assignments (samples provided in the Appendix). The eleven cases were subjected to cross case analysis. Several patterns emerged regarding the relationship between the characteristics of preservice teachers' analysis of socioscientific issues and the extent to which their stances were sustainable. The patterns are summarized in the next section.

Results

This section begins with a report of the number of rationales preservice teachers used from each of the dimensions of the sustainability triad in their analysis of the selected socioscientific issues. This report is followed by a description of the types of considerations used to inform the preservice teachers' decisions. Then, an account of the congruencies, conflicts, and values that characterized the preservice teachers' analysis is provided. The section ends with a description of the extent to which the preservice teachers' stances were sustainable.

Dimensions of the Sustainability Triad

An average of 12.36 rationales were used to support each of the stances taken in the eleven Does it Matter assignments. The majority of the rationales,

46%, were aligned with the economic dimension of the sustainability triad. Of the remaining, 28% were aligned with the social dimension and another 26% were aligned with the environmental dimension.

The majority (55%) of the Does it Matter assignments reflected rationales from the three dimensions of the Sustainability Triad. Five assignments (36%) reflected rationales from two of the triad's dimensions: economic and social. One assignment, Allow Cats, presented rationales from the environmental dimension only. While all but one assignment contained rationales consistent with the economic dimension, three assignments (E-Coal, No to Weapons II, and Yes to Weapons) did not contain rationales consistent with the environmental dimension (Table 2). Only one assignment, E-Biofuel, did not contain rationales consistent with the social dimension.

Economic Considerations

The rationales within the economic dimension were grouped into three subcategories of considerations (Table 3). The subcategories represented considerations of growth or reduction in national wealth, corporate wealth, and/or personal wealth in the form of money, property, and jobs. National wealth was affected by revenue and expenditures resulting from taxes, military spending, research and development, imports, and/or exports. Corporate wealth was affected by revenue and expenditures from start-up businesses, corporate research and development, technological innovations, patents, sales, production costs, and/or materials production and sales. Personal wealth was affected by the loss and gain of money, property, and/or jobs.

Growth in personal wealth emerged as the most frequently used consideration, followed by growth in corporate wealth. Reduction in national wealth was used least frequently within the economic dimension. Table 3 presents the number of considerations used from each of the subcategories of the economic dimension of the sustainability triad.

Social Considerations

The rationales within the social dimension were grouped into four subcategories of considerations (Table 3). The subcategories represented considerations of the quality and availability of health care and food, a happy life, and/or welfare and rights of individuals and societies. Quality and availability of health care were affected by increased possibilities of injury, disease, birth defects, allergies, and/or overall well-being. Availability of food was influenced by the increase or lack of opportunities to procure more, and/or nutritious food. Leading a happy life was affected by the availability of stable social interactions and/or availability of recreational opportunities. The welfare and rights subcategory encompassed attention to human exploitation, community rights and activism, and/or social welfare and health.

Threats to the quality and availability of health care emerged as the most frequently used consideration in the social dimension (Table 3).

Considerations of the welfare and rights of societies and groups came next. Threats to a happy life were used least frequently.

Environmental Considerations

The rationales within the environmental dimension were grouped into four subcategories of considerations (Table 3). The subcategories represented considerations of populations, diversity of species, pollution, and/or resources. Considerations about populations were concerned with impacts on population growth, control, maintenance, and overpopulation. Considerations about diversity of species were concerned with the discovery or creation of new species, and/or extinction threats to existing species. Considerations about pollution were concerned with the impact of emissions and other factors that restore, maintain, disrupt, or destroy ecosystems. Considerations about resources focused on the availability and use of renewable and non-renewable resources.

Pollution emerged as the most frequently used consideration in the environmental dimension (Table 3). Considerations about population management came next. Considerations about species were used least frequently.

Characteristics of Socioscientific Issue Analysis

The preservice science teachers' analysis of socioscientific issues was characterized by conflicts, congruencies, and values to various extents.

C*onflicts.* Conflicts between dimensions of the Sustainability Triad were apparent in the preservice teachers' analysis as follows (see Table 4):

- None (n = 4)
- Economic/Social (n = 3)
- Economic/Environmental (n = 1)
- Social/Environmental (n = 1)
- All (n = 1)

An example of a conflict between the social and environmental dimensions is apparent in the Allow GMP assignment, where the preservice teachers concluded that the availability and improved quality of food and health at a national and international level might come at the cost of biodiversity. An example of a conflict between the economic and social dimensions is apparent in the No Weapons I assignment, where the preservice teachers cited a reduction in corporate and national wealth as one consequence of their decision and more global harmony as another. An example of a conflict between the economic and environmental dimensions is illustrated in the Allow Logging assignment, where an increase in personal and corporate wealth occurs as habitats continue to be destroyed.

Congruencies. Congruencies between dimensions of the Sustainability Triad were also apparent in the preservice teachers' analysis as follows (see Table 4):

- None (n = 4)
- Economic/Social (n = 5)
- Economic/Environmental (n = 1)
- Social/Environmental (n = 1)
- All (n = 1)

Table 4
Conflicts Congruence and Values

Assignment	Conflict	Congruence	Values
Allow Hunting	None	All	Only humans vs. All life has value Self-interest vs. Community interest Short-term vs. Long-term vision
No Weapons I	Eco / Social Eco / Envi	Social / Envi	Self-interest vs. Community interest Only humans vs. All life has value
Yes Weapons	Eco / Social	None	Self-interest vs. Community interest Short-term vs. Long-term vision
No Weapons II	Eco / Social	None	Self-interest vs. Community interest Short-term vs. Long-term vision
E-Coal	Eco / Social	Eco / Social	Short-term vs. Long-term vision Self-interest vs. Community interest
E-Biofuel	None	Eco / Envi	Self-interest vs. Community interest Short-term vs. Long-term vision
E-Nuclear	None	Eco / Envi	Short-term vs. Long-term vision Self-interest vs. Community interest
Allow Logging	All	None	Only humans vs. All life has value
Allow GMP	Social / Envi	Eco / Social	Self-interest vs. Community interest
Allow Cats	None	None	Only humans vs. All life has value
Ban Cats	Eco / Social	Eco / Envi	Only humans vs. All life has value Short-term vs. Long-term vision

An example of an attempt at congruency between the economic and social dimensions is apparent in the E-Coal assignment, where the use of coal continued to support personal and corporate wealth as it maintained the quality of life of individuals and communities. An example of a an attempt at congruency between the economic and environmental dimensions is illustrated in the E-Nuclear assignment, where cheaper energy and additional jobs to reprocess fuel contribute to personal, corporate and national wealth and independence while at the same time decreasing pollution. An example of a congruency between the social and environmental dimensions is apparent in the No Weapons I assignment, where social interests and global welfare go hand in hand with decreased pollution.

Values. A variety of values were apparent in the preservice teachers' analysis of socioscientific issues as follows (Table 3):

- Self-interest vs. Community interest (n = 8)
- Short-term vision vs. Long-term vision (n = 7)
- Only humans have value vs. All life has value (n = 5)

An example of a statement reflecting one end of the "Only humans have value vs. All life has value" continuum from the Allow Hunting assignment is, "Hunting results in the murder of innocent animals or the violent and inhumane treatment of animals like hounds." Another example from the Ban Cats assignment states, "Cats need exercise and space." Examples closer to the other end of the continuum include the Allow GMP assignment statement "GMPs result in healthier animals that produce more nutritious eggs, milk, and meat" and the Allow Logging assignment's "We may end up losing plants and animals with potential medicinal benefits."

Examples of statements reflecting one end of the "Short-term vision vs. Long-term vision" continuum are, "There are enough fossil fuels to maintain quality of life for next 200-300 years" (E-Coal) and "Future generations need to monitor waste storage" (E-Nuclear). An example of a statement that reflects the values of the "Self-interest vs. Community interest" continuum is, "It is important to keep harmony between nations" (No Weapons II).

Sustainability of Stance

Few of the preservice teachers' adopted stances reflected an attempt at sustainability. Most of the preservice teachers' adopted stances in the Does it Matter assignments were supported by a majority of pro rationales. The only exception, the Allow Cats stance, was supported by an equal number of pro and con rationales. Considerations of all dimensions of the Sustainability Triad, conflicts, congruencies, and values emerged as indicators of sustainability.

One assignment, Allow Hunting, reflected a stance in the sustainability domain characterized by (a) rationales from all dimensions of the triad, (b) congruence between all dimensions of the Sustainability Triad, (c) an absence of conflicts, and (d) harmony in values. Corporate and national interests were not in conflict with the interests of the individual and community, or the belief that all life has value.

Four assignments (No Weapons I, E-Nuclear, Allow GMP, and Ban Cats) reflected an attempt at sustainability characterized by (a) rationales from all dimensions of the sustainability triad, (b) congruence between some of the dimensions of the sustainability triad, and (c) conflicts between some of the dimensions of the triad.

Five assignments reflected stances that were not sustainable. These assignments were characterized by rationales from only one or two dimensions of the Sustainability Triad. These assignments were E-Coal, E-Biofuel, Yes Weapons, No Weapons II, and Allow Cats. A sixth assignment, Allow Logging, also reflected an unsustainable stance that was characterized by conflicts and a lack of congruence between all dimensions of the Sustainability Triad.

Discussion

The findings of this study indicate that more than half of the preservice teachers used rationales aligned with all three dimensions of the Sustainability Triad. This finding implies that these preservice teachers were intuitively oriented to consider sustainability as they analyzed and made decisions about socioscientific issues. The majority of the remaining preservice teachers either considered rationales from the economic and social, or the economic and environmental dimensions of the triad as they analyzed and made decisions about socioscientific issues. These preservice teachers seemed to be less oriented to consider sustainability in their analysis. Only one group of preservice teachers did not seem to be oriented to reason from a sustainability perspective at all. This third group of teachers only considered rationales from the environmental dimension.

The findings of this study also indicate that the economic dimension constituted the largest source of rationales for the preservice teachers. This finding implies that as a group, the preservice teachers in this study were oriented to think of economic considerations to a large extent. The preservice teachers seemed to be oriented to think of social and environmental considerations to a lesser degree.

Finally, except for one, the preservice teachers' adopted stances in this study were not sustainable for two reasons: not all dimensions of the Sustainability Triad were considered, and the relationship between the conflicts, congruencies, and values characterizing the preservice teachers' analyses was not considered. As mentioned previously, many of the preservice teachers did not intuitively consider all the dimensions of the sustainability triad. Instruction about sustainability using the Sustainability Triad may help address this issue. Furthermore, the preservice teachers did not seem to be aware of the conflicts and/or congruencies that characterized their analysis. Without being aware of the conflicts and congruencies among the social, environmental, and economic dimensions, the preservice teachers did not have the opportunity to discuss whether their decisions met Fien and Trainer's (1993) criterion of maintaining, supporting, or carrying the weight or burden of all three dimensions of the sustainability triad over the long term.

Additionally, the preservice teachers did not seem to explicitly consider the values they, as stakeholders, and the stakeholders they cite bring to the analysis and the decision. This lack of awareness of values seems to have made it harder for the preservice teachers to, as Herremans and Reid (2002) state, find common ground for reaching a sustainable decision. One other possibility for why the preservice teachers' decisions were not sustainable may be that they do not value sustainability as a goal for policy and practices. A lack of understanding of the concept of sustainability may be an underlying cause for this possibility.

Recommendations

The findings of this study support several recommendations for the teaching of sustainability in the context of science teacher education. A first recommendation calls for science teacher education programs that incorporate explicit instruction about sustainability, the Sustainability Triad, and related constructs in content courses. Content courses may emphasize the relationship between sustainability, science, technology, and ecology by giving examples of sustainable practices, unsustainable practices, and consequences of both. Content courses may also engage preservice teachers in analyzing community-based cases using the Sustainability Triad. Herremans and Reid (2002) provide an example of such a case and its analysis based on a Canadian park.

A second recommendation calls for science teacher education programs that incorporate explicit instruction about sustainability, the Sustainability Triad, and related constructs in science education courses. One way of addressing the concept of sustainability in a science methods course consists of explicit instruction about the Sustainability Triad in the context of socioscientific issues. The Sustainability Triad can serve as an advance organizer (Ausubel, 1978) to be shared with preservice teachers prior to discussions of socioscientific issues. As an advance organizer and framework for analyzing socioscientific issues, the sustainability triad has the potential to help scaffold the types of higher order learning necessary to promote understanding, recognition, and action for sustainable development.

Conclusion

Preservice teachers may intuitively draw on the dimensions of the Sustainability Triad as they analyze and make decisions about socioscientific issues. However, a large number of preservice teachers may not consider one or more of the dimensions of the triad due to inadequate understanding of the concept of sustainability or orientations to reason from a limited number of perspectives. Failure to consider the economic, social, *and* environmental domains to analyze socioscientific issues and concomitant projects, activities, regions, or processes will undoubtedly result in less sustainable decisions and actions. The use of the Sustainability Triad as an advance organizer for the discussion of socioscientific issues is recommended.

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Biographical statement

Dr. Danielle Dani holds a B.S. in Biology and a M.S. in Biology. She received her Ed.D. in Curriculum and Instruction from the University of Cincinnati. Dr. Dani teaches graduate and undergraduate courses in science education and teacher education. Her research examines the knowledge, beliefs and practices necessary for teaching science as inquiry, promoting environmental and scientific literacy in the 21st century, and engaging in reflective, high-quality, student-centered teaching.

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Appendix

Allowing Hunting

	Economic	Social	Environmental
Pro	• Provides tax revenue • Provides revenue from hunting licenses • More income from ammunition sales • More income from camouflage attire sales	• More sources of food • Stronger sense of family • More bonding time with friends • Availability of recreational activity	• Provides funds to manage parks • Hunting seasons and regulations protect wildlife populations
Con		• More hunting related accidents • More hunting related deaths	
Conflict and/or Congruence	No Conflict	Economic, social, and environmental congruence.	
Values	Only humans vs. All life has value		

Allow Logging/Deforestation

	Economic	Social	Environmental
Pro	• Provides jobs. • Provides homes. • Provides usable land for individual farmers growing crops. • Provides usable land for companies growing crops. • Provides usable land for animal pasture. • Provides a source of income for many individuals • Supports a variety of industries • Results in the establishment of recycling companies.	• More sources of food. • Provides schools. • Provides tools. • Rallies and unionizes community members.	
Con		• Results in political activism. • Results in the loss of plants and animals with potential medicinal benefits.	• Destroys habitats. • Causes soil erosion. • Causes flash flooding. • Results in the loss of plants and animals (extinction).
Conflict and/or Congruence	Economic / Environmental / Social conflict	Economic / Social congruence	
Values	Only humans vs. All life has value		

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